Warm Weather In-House Drying of Poultry Manure

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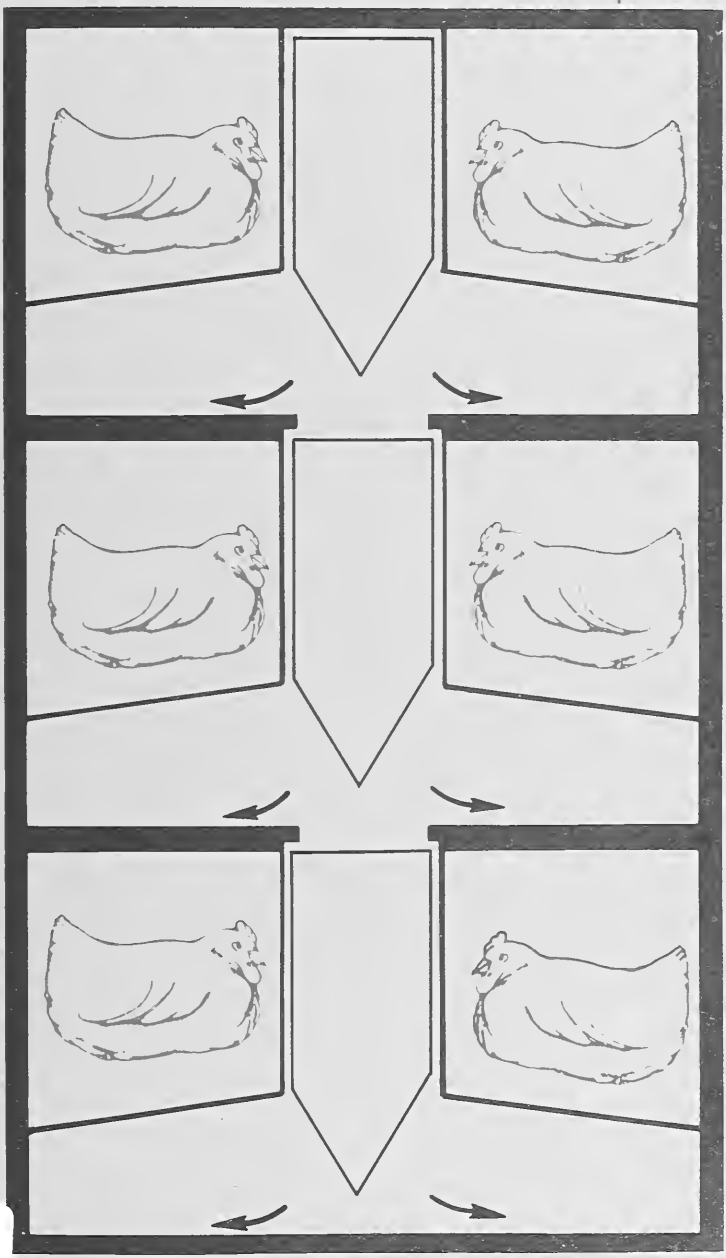

West Virginia University Agricultural Experiment Station

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Poultrymen must conform with current efforts to eliminate, or at least materially reduce, environmental pollution. Energy in all conventionally used forms is also in short supply. In the past, heat in ventilation air and from the birds has been wasted during warm weather operations.

Energy is needed to transport materials of any kind, and manure is no exception. If a substantial portion of water can be evaporated from manure before any attempt is made to move it, less energy will be required. To produce such evaporation, using the sensible heat produced by the birds, required a ventilation system which would constantly blow air over the manure, and a belt conveyor to remove manure simultaneously from beneath three tiers of cages.*

OBJECTIVES

The objectives of this research were to: (1) determine, using six different air flow rates, how much water could be evaporated from the manure as it accumulated for 24 to 144 hours; (2) determine the amount of heat produced by the birds which was used to evaporate water; (3) determine the amount of water added to ventilation air on a per bird basis; and (4) determine the effect the evaporated water had on the relative humidity of the room air.

Ventilation and Conveyor Systems

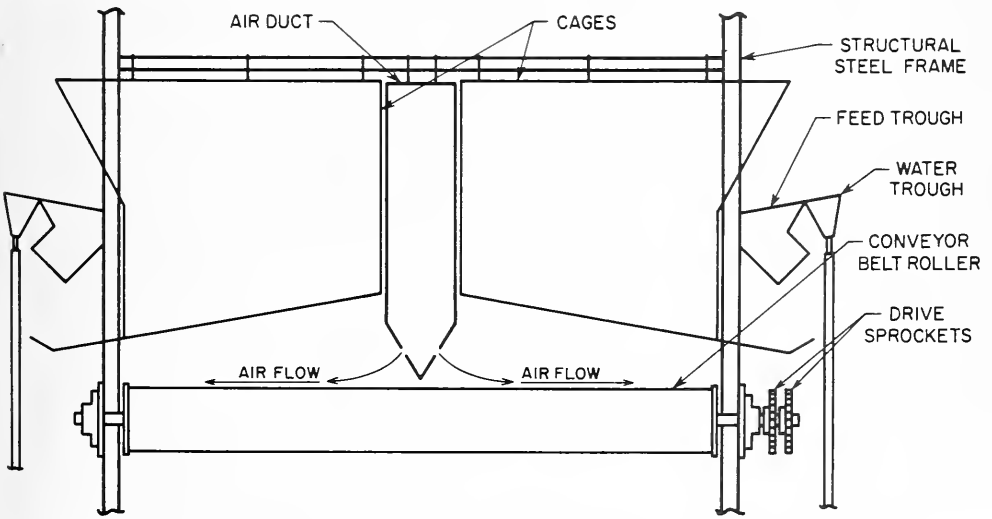
Only a brief description of the ventilation and conveyor systems will be given since a complete description was made in a previous report.** Basically, a ventilation duct was placed between two rows of cages so as to blow air over the manure as it accumulated on the plastic (Mylar) conveyor belt (Figure 1). After 18 months of use, the belt showed no sign of deterioration.

Air Flow Rates

It was essential to have accurate data for air flow, which was recirculated and exhausted from the chamber. Two fans were used. One fan exhausted air from the chamber and the other recirculated a portion of the in-house air through the duct system between cages.

*A complete description of the ventilation and conveyor systems was reported by A. D. Longhouse in *Partial In-House Drying and Mechanical Removal of Manure From Caged Laying Hens*, Bulletin 632T, WVU Agricultural Experiment Station, September 1974.

**Bull. 632T, *op. cit.*



CROSS-SECTION OF AIR DUCT BETWEEN TWO ROWS OF CAGES AND CONVEYOR BELT BELOW FOR ACCUMULATION AND REMOVAL OF MANURE

Figure 1

Air flow rates were measured at two locations in the ventilation systems. Air flow through the six room exhaust ports was measured with a hot wire anemometer. Air flow rates through the recirculation system were measured with a pitot tube and inclined draft gauge. In each case, the procedures followed conformed, as closely as possible, to standard practice. These measurements were made each time the orifice plates were changed.

No attempt was made to control or limit the exhaust air. However, the use of orifice plates ahead of the fan, which were used to vary the rates of air flow through the duct system, affected the rate of exhaust air. As the rate of recirculated air was increased it caused a decrease in exhaust rate (Table 1). When no air was recirculated the maximum rate of air exhausted was 1520 cm^3/sec (3.22 ft^3/min) per bird. As the recirculated air flow rate was increased to 1836 cm^3/sec (3.89 ft^3/min) per bird, the exhaust rate decreased to 1152 cm^3/sec (2.44 ft^3/min) per bird (Table 1). These air flow rates were corrected to standard air density of 1.20 kgs/m^3 (0.075 lbs/ft^3) which corresponds to dry air at 21°C (70°F) and 760 mmHg (29.92 in. Hg.)* No corrections were made for air flow data collected during the tests. Rather, data were presented that would occur during normal operations of poultry house management.

Weight and Water Content of Fresh Manure

Water content of the fresh manure had to be determined so as to obtain accurate data for the amount of water removed from the accumulation on the conveyor belts under the cages. Also, it was desirable to know the rate and quantity of manure defecated to better determine manure handling and management programs.

At first, water content analyses were made immediately after the lights were turned on at 8 a.m. Invariably, the water content exceeded 80 percent (w.b.). (Most literature references indicate the water content to be about 75 percent.) To be more certain of the water content of freshly defecated manure, two tests were made by removing and drying the manure at two-hour intervals for 24 hours. The first test was made with young laying hens at relatively high egg production (82 percent). The second test was made with essentially the same laying hens 15 months later when egg production was much lower (36 percent).

Results of the two tests were quite similar (Table 2 and Figure 2). In both tests, the water content of manure defecated during the first two hours after the lights were turned on was above 80 percent (w.b.) and did not drop below 80 percent (w.b.) until late afternoon. By midnight, it began to rise until it was again over 80 percent (w.b.).

Maximum defecation occurred during the first two hours the lights were on. This was partially due to the high water content. After that there was a steady decline in the defecation rate until the lights were turned off at 10:00 p.m. This, too, was partially due to the decreasing water content of the manure (Table 2 and Figure 2). After the lights were turned off at 10:00 p.m. there was a substantial decrease in the rate of defecation, particularly for older laying hens.

The data have been presented for each two-hour interval to show the quantity and percent water content (w.b.), which ranged between 2.402 kg (5.28 lbs) with 85.22 percent water (w.b.) for the 8 - 10 a.m. period, to a low of 0.706 kg (1.55 lbs) with 79.34 percent water (w.b.) for the 12 - 2 a.m. period. Essentially the same results were recorded for the older laying hens (consult columns 2-5, Table 2). The rate of accumulation revealed the quantity and average water content (percent w.b. not weighted) at any time after 8 a.m. (consult columns 6-9, Table 2).

For the two tests the average weight for fresh manure was 14.6 kg (32.12 lbs) with an average water content of 80.86 percent (w.b.).** The graphical presentation of these data shows the similarity in the two tests (Figure 2).

When the data were analyzed to determine the amount of water evaporated before the manure was removed from the chamber, fresh manure was assumed to contain 80 percent (w.b.) water, based on the results of these two tests.

Weight and Percent of Water Evaporated

After the moisture content of fresh manure was determined, it was possible to calculate the weight and percent of water evaporated. By using the percent moisture content and weight of the manure when it was removed, the quantity of water evaporated was determined. It was important to have an accurate measurement of the water evaporated in order to measure the effect on relative humidity and use of sensible heat in the evaporation process.

Using 100 kg(lb) of fresh manure containing 80 percent water and 20 percent solids, the weight and percent of water evaporated at any moisture content may be estimated between 80 and 10 percent (Table 3). For instance, assume manure contained 75 percent water when it was removed. Referring to Table 3 shows that on the basis of 100 kg (lb), 20 kg (lb) of water were evaporated, which was a 25 percent reduction in water content. Weight of the water evaporated was also the percent of weight reduction of the manure. The weight of the solids was assumed to remain constant. Manure containing 50 percent moisture would have a weight reduction of 75 percent (Table 3), which provides a substantial reduction in the weight of material to move and a more desirable product to handle.

Data in Table 3 are presented graphically in Figure 3. The upper curve (water) may be used to estimate the percent of water removed when the percent moisture content is known. As an example, manure containing 50 percent water will have lost 75 percent of its original moisture content. The lower curve (manure) represents the percent reduction in the weight of manure at any given

*As recommended in the Test Code for Air Moving Devices, AMCA Standard 210-67.

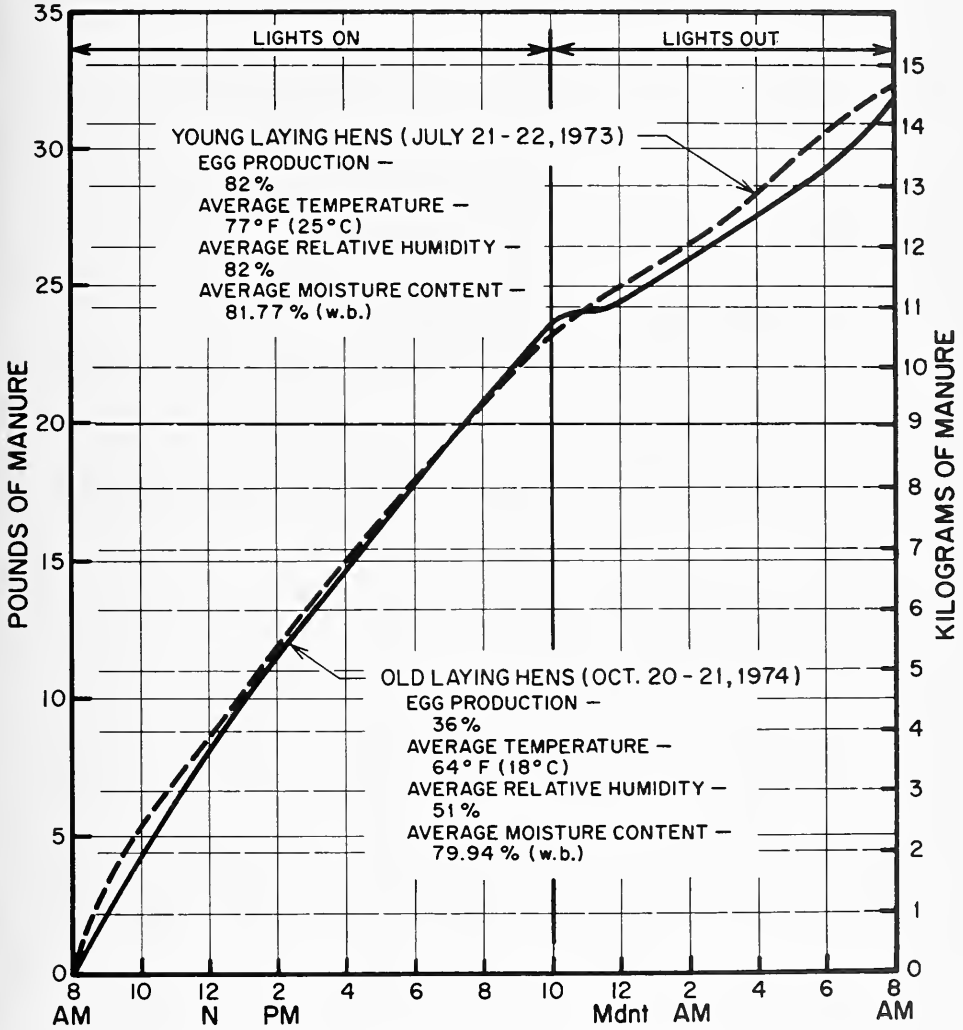
**The manure was dried for not more than 24 hours in a forced draft oven with the thermostat set at 100°C.

moisture content between 80 and 10 percent. Manure containing 50 percent moisture at time of removal had a weight reduction of 60 percent.

EVAPORATION OF WATER

Time, temperature, relative humidity and rate of air flow affected the rate and quantity of water evaporation from the manure as it accumulated on the conveyor belts under the cages. In this study, only the time manure was allowed to accumulate and the rate of air flow were controlled. Temperatures and humidity fluctuated with changes in ventilating air and to some extent with the rate of flow of exhaust air.

The length of time manure was allowed to accumulate ranged from a minimum of 24 hours to a maximum of 144 hours. The rate of recirculated air flow over the manure ranged from zero to 1836 cm^3/sec (2.89 ft^3/min).



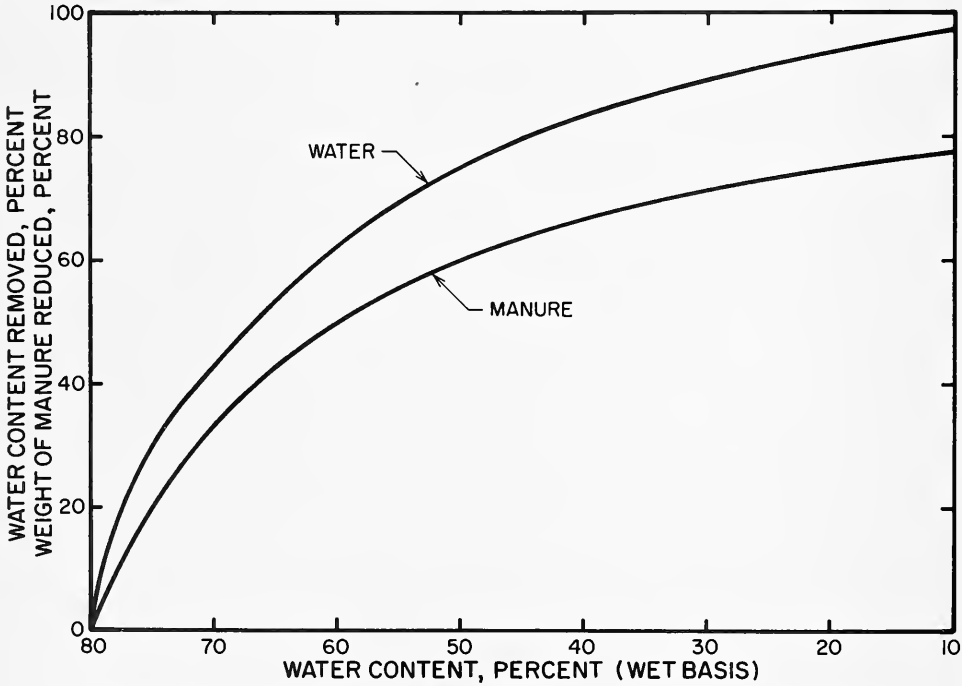
RATE AND WEIGHT OF ACCUMULATION OF FRESH MANURE FROM 100 LAYING HENS FOR 24 HOURS

Figure 2

The data analysis presented in the following tables was based on weight and water content of the manure at the time it was removed from conveyor belts. All of the manure was oven-dried at about 100°C for 24 hours. Assuming fresh manure contained 80 percent water, oven-dry manure was divided by .20 to obtain the fresh weight. Then the weight and percent of the water evaporated in-house could be determined. The variations in fresh and dry weights were due to changes in the number of birds housed at the time of each test. The time and date of each test were varied or randomized to take advantage of changing weather conditions.

Water evaporated from the manure that accumulated for 24 hours with different air flow rates ranged from 19 percent (zero air flow) to 75 percent with the maximum air flow of 1836 cm^3/sec (3.85 ft^3/min) (Table 4). The chamber temperatures ranged between 20°C (68°F) and 26°C (79°F); relative humidity varied between 54 and 77 percent. Relative humidity appeared to have the greatest influence on the quantity of water evaporated. The least water evaporated occurred when relative humidity was the highest (77 percent), except when there was no air flow. With the lowest air flow rate of 845 cm^3/ sec (1.79 ft^3/min), 59 percent of the water was evaporated. The average temperature and relative humidity were 21°C (69°F) and 54 percent (Table 4). The average temperature and relative humidity for the seven 24-hour tests were 23°C (73°F) and 63 percent.

When manure accumulated for 48 hours under the cages before it was removed, 79 percent of the water was evaporated with the maximum air flow rate of 1836 cm^3/sec (3.89 ft^3/min) (Table 5). At the minimum air flow rate of 845 cm^3/sec (1.79 ft^3/min), 71 percent of the water was evaporated. When no air was blown over the manure, 28 percent of the water was evaporated. During the 48-hour period when the air flow rate was 1671 cm^3/sec (3.54 ft^3/min), 88 percent of the water was evaporated. Relative humidity was 48 percent. Moisture content of the manure at the time of removal was 32 percent. Less water was removed at the maximum air flow rate of 1836 cm^3/sec (3.89 ft^3/min) than at the 1671 cm^3/sec (3.54 ft^3/min) air flow rate. This was due to the lower temperature of 16°C (60°F) and the higher relative humidity of 58 percent (Table 5). Average temperature and relative humidity for the seven 48-hour tests were 21°C (69°F) and 58 percent, respectively.



PERCENT OF WATER EVAPORATED AND WEIGHT REDUCTION OF POULTRY MANURE AS WATER CONTENT IS REDUCED FROM EIGHTY TO TEN PERCENT (WET BASIS).

Figure 3

Manure which accumulated for 72 hours lost 38 percent of the water when no air was blown over it (Table 6). When the maximum rate of air flow of 1836 cm^3/sec (3.89 ft^3/min) was blown over the manure, 85 percent of the water was evaporated. During the time 1071 cm^3/sec (2.27 ft^3/min) of air was blown over the manure only 72 percent of the water was evaporated. The high relative humidity of 76 percent was responsible for the lower evaporation rate. With this exception, evaporation exceeded 75 percent for the six rates of air flow (Table 6). The average temperature and relative humidity for the seven 72-hour tests were 22°C (71°F) and 64 percent.

After 96 hours of accumulation, the manure contained less than 50 percent moisture for the four rates of air flow, Table 7.* The 73 percent relative humidity that prevailed during the maximum rate of air flow of 1836 cm^3/sec (3.89 ft^3/min) depressed the evaporation rate to 77 percent. The same percentage of evaporation occurred at the lowest air flow rate of 1326 cm^3/sec (2.81 ft^3/min) when the relative humidity was 62 percent. Water evaporation for the four rates of air flow averaged 80 percent. The average temperature and humidity for the four 96-hour tests were 26°C (79°F) and 65 percent.

After 120 hours the accumulated manure contained 38 to 40 percent moisture when it was removed for the four rates of air flow (Table 8). Again the higher relative humidity of 73 percent, coupled with the lowest rate of air flow of 1326 cm^3/sec (2.81 ft^3/min), accounted for less water being evaporated. Excluding this air flow rate, 85 percent of the water was evaporated before the manure was removed. Average temperature and humidity for the four 120-hour tests were 26°C (79°F) and 65 percent.

The final and maximum length of time of 144 hours manure was allowed to accumulate resulted in 82 percent of the water being evaporated (Table 9). As long as the relative humidity remained below 70 percent, water evaporation exceeded 80 percent. The average temperature and relative humidity for the four 144-hour tests were 25°C (77°F) and 66 percent.

Heat Available and Used to Evaporate Water

Two sources of sensible heat were available to evaporate water from the manure: heat from the birds and heat in the ventilating air. Only sensible heat produced by the birds was used in the analysis, principally to determine if any remained to heat the ventilating air during cooler weather. USDA (Beltsville) calorimetric data were used to calculate the sensible and latent heat produced by laying hens.** Calorimetric-psychrometric comparisons were made periodically to determine validity of data.*** As long as these relationships were within 10 percent of each other, data were considered acceptable. Many of the evaluations were within five percent of each other. The number of birds involved ranged from 113 to 144.

The sensible heat produced by the birds, like other homeothermic animals, varied with changes in the ambient temperature. Thus, it was necessary to make a complete analysis for each test to determine the sensible heat produced by the birds and the portion used to evaporate water from the manure.

Data required to calculate the percent of sensible heat produced per hour by the birds used to evaporate water from the manure were as follows:

1. Average number of birds for each test (time manure accumulated).
2. Average temperature for each test (time manure accumulated).
3. Average weight of birds kg (lb).
4. Total heat produced per kg (lb) of bird housed based on room temperature (Appendix A).
5. Percent of total heat that was sensible (Appendix A).
6. Quantity of water evaporated from the manure.
7. Heat of vaporization, 611 kcal/kg (1100 btu/lb).
8. Moisture content of fresh manure.
9. Moisture content of manure at time of removal.

At the maximum rate of air flow of 1826 cm^3/sec (3.89 ft^3/min) per bird, the room temperature varied between 16°C (60°F) and 28°C (83°F). This rather wide range in temperature caused the available sensible heat from the birds to vary between 54 and 71 percent (Table 10). Therefore, the amount of heat used to evaporate water from the manure varied between 30 and 48 percent. The 48 percent occurred when the room temperature was highest at 28°C (83°F). Thus the least amount of sensible heat was produced during this test (Table 10).

During the test when the rate of air flow was held constant at 1671 cm^3/sec (3.54 ft^3/min) per bird room temperature varied between 21°C (69°F) and 28°C (83°F) (Table 11). The smaller difference in room temperature caused a lesser variation in the amount of sensible heat produced by the birds. This varied between 58 and 67 percent, while the amount used to evaporate moisture ranged between 42 and 46 percent.

The least amount of heat used occurred during the 24-hour accumulation period when there was an insufficient amount of manure on the conveyor belts to efficiently use available sensible heat (Table 11).

Unlike most of the tests, average room temperature remained virtually constant at 25°C (77°F) to 26°C (79°F) for this test when the air flow rate was 1473 cm^3/sec (3.12 ft^3/min) per bird. Thus, available sensible heat remained nearly constant at 58 to 60 percent. There was a 17 percent difference in the amount of sensible heat used. The low of 36 percent occurred during the 24-hour accumulation period. The high of 53 percent was used

*Beginning with this test, collecting data for the three lower rates of air flow and no air flow were discontinued to permit completion of the research before cold weather. The warm weather research was completed October 20, 1974.

**Ota, H. and McNally, E. H. 1961. Poultry Respiration Calorimetric Studies on Laying Hens–Single Comb White Leghorns, Rhode Island Reds and New Hampshire Cornish Crosses. Agr. Res. Service, USDA, 42-43.

***Calorimetric measurements refer to heat and moisture produced by the birds. Psychrometric measurements involved the heat and moisture content of the inlet and exhaust air. The differences in heat and moisture content of the inlet and exhaust air should be equivalent to the heat and moisture produced by birds and the moisture evaporated from the manure.

when there were 113 birds in the house. In all of the 33 tests, this is the only time the sensible heat used to evaporate water exceeded 50 percent (Table 12).

With reduction of the constant air flow to 1326 cm^3/sec (2.81 ft^3/min) per bird, there was a substantial decrease in the quantity of sensible heat used to evaporate water (Table 13). The temperature range of 10°C (67°F) to 25°C (77°F) was slightly lower than for previous tests. Thus the available sensible heat of 60 to 68 percent was slightly higher. The proportion of sensible heat available which was used to evaporate water was reduced to a range of 24 to 42 percent. This was due, in part, to the slight increase in available sensible heat, and, in part, to the decrease in air flow rate (Table 13). The latter was considered to be the most important factor.

For the air flow rate of 1073 cm^3/sec (2.27 ft^3/min) per bird, the accumulation periods were for 24, 48, and 72 hours.* Compared with the previous test, the room temperature was slightly lower with a range of 21°C (69°F) and 24°C (76°F) which produced a higher level of available sensible heat of 61 to 67 percent (Table 14). The sensible heat used to evaporate water ranged between 32 and 35 percent. This was slightly more than for the air flow rate of 1326 cm^3/sec (2.81 ft^3/min) reported above (Table 13) and was due to a higher quantity of available sensible heat.

The 845 cm^3/sec (1.79 ft^3/min) was the minimum air flow rate used, except for the last test when no recirculated air was blown over the manure. Room temperatures ranged between 21°C (69°F) and 26°C (79°F), a difference of 5°C (9°F) which accounted for the variation of 58 to 67 percent in sensible heat available (Table 15). In turn, this influenced the amount of heat utilized to evaporate water. The high of 67 percent occurred during the 24-hour accumulation period, but only 24 percent was used. This was due, in part, to the small quantity of accumulated manure during this period. The high utilization of 43 percent of the available sensible heat occurred during the 72-hour accumulation period, when the least amount of sensible heat was available. The difference was due to room temperature and manure accumulation time (Table 15).

The final test was made by stopping all recirculated air flow over the manure (Table 16). In comparison with the previous test, the air over the manure was virtually stagnant, except for air movement created by bird activity and the usual air movement which occurred with conventional poultry house ventilation systems. As in previous tests, the room temperature range was similar. It ranged between 19°C (67°F) and 25°C (77°F). At this temperature range the available sensible heat was 60 to 68 percent of the total heat. However, only 9 to 15 percent of sensible heat was used to evaporate water (Table 16). Again, the least evaporation of 9 percent occurred during the 24-hour accumulation period when the room temperature was 25°C (77°F) as compared with 15 percent for the 72-hour accumulation period which had an average room temperature of 22°C (71°F). It is evident the 24-hour accumulation period was not long enough to achieve efficient use of the sensible heat (Table 16).

*At this time in the conduct of the research, the decision was made to limit the tests to the three accumulation periods of 24, 48, and 72 hours. The data in the preceding test (Table 13) indicated the minimum rate of air flow to obtain maximum evaporation (based on sensible heat used) had been exceeded. Also, the possibility existed that the remaining warm weather conditions might end before all of the tests could be completed. As it was, the tests did not end until October 20, 1974.

Weight and Percent of Water Evaporated from Manure

The quantity, or weight, of water evaporated depended on the rate of flow and relative humidity of the air and length of time manure accumulated under the cages. The higher air flow rates had less effect on the quantity of water removed than the other two parameters. The rate of air flow became a more important factor when it was reduced to and below 1326 cm^3/sec (3.89 ft^3/min) per bird. For each of the tests, evaporation was less for the 24-hour accumulation period than any of the longer periods of accumulation.

At the maximum air flow rate of 1836 cm^3/sec (3.89 ft^3/min) per bird, 75 to 85 percent of the water was evaporated from the manure. Thus, the weight of the manure was reduced 10.22 kg (22.48 lbs) for 24 hours of accumulation, to 61.27 kg (134.79 lbs) for 144 hours of accumulation (Table 17). During this test the temperature ranged from 16°C (60°F) to 28°C (83°F) and relative humidity from 58 to 73 percent. The comparatively high relative humidity of 73 percent during the 96 hours of manure accumulation reduced the water evaporated to 77 percent. As long as the average relative humidity remained below 70 percent, evaporation exceeded 80 percent, except for the shortest periods of manure accumulation. During these tests, moisture content of the manure at the time of removal was 50 percent or less (Table 17).

During the test when the air flow rate was held constant at 1671 cm^3/sec (3.54 ft^3/min) per bird, water evaporated from manure ranged between 72 and 88 percent when manure retention time was 24 to 144 hours (Table 18). Average temperature and average relative humidity varied between 21 and 28°C (69 and 83°F) and 48 to 63 percent, respectively. Even though the relative humidity was only 58 percent during the 24-hour accumulation period, the water evaporated was 72 percent, which was considerably lower than the quantity removed when the accumulation time was longer. Except for the 24-hour accumulation time the moisture content of the manure at time of removal was well below 50 percent (wet basis). (When the water evaporated is 80 percent or above, total fresh weight of the manure is reduced 64 percent or more at the time it is removed (Figure 3).) Since the relative humidity remained below 70 percent it was possible to achieve evaporation in excess of 80 percent, except when the manure accumulation time was 24 hours (Table 18).

With the air flow rate reduced to 1473 cm^3/sec (3.12 ft^3/min) per bird, the quantity of water evaporated from the manure remained above 80 percent. The exception was

for the 24-hour accumulation time when the evaporation was 65 percent (Table 19). Average temperature ranged between 25°C (77°F) and 26°C (79°F) and average relative humidity fluctuated from 57 to 67 percent. Also, water content of the manure at the time of removal was 45 percent (wet basis) or lower, except for the 24-hour period when it was 58 percent (wet basis).

Reducing the air flow rate to 1326 cm^3/sec (2.81 ft^3/min) lowered the quantity of water evaporated to less than 80 percent (Table 20). Since there was no attempt to control temperature and relative humidity of the incoming air, data indicate that an air flow rate of 1326 cm^3/sec (2.81 ft^3/min) may be the lowest limit in achieving maximum water removal from the manure. The average temperature range of 19 to 25°C (67 to 77°F) was slightly below those in preceding tests. Also, average relative humidity exceeded 70 percent for three of the six tests, which affected water evaporation. However, for the 96 hours of accumulation, the temperature was 25°C (77°F), relative humidity was 62 percent, and water evaporated was down to 77 percent. This would imply that the minimum air flow rate to achieve maximum water evaporation had been slightly exceeded. At this air flow rate, moisture content of manure at the time of removal was below 50 percent (wet basis), except for the 24-hour accumulation time when it was 66 percent (wet basis). The short accumulation time of 24 hours and the high relative humidity of 77 percent resulted in only 52 percent of the water being evaporated (Table 20).

Beginning with the air flow rate of 1071 cm^3/sec (2.27 ft^3/min), manure accumulation time was limited to 72 hours to allow completion of tests before cold weather was encountered (Table 21). The temperature ranged between 21 and 24°C (69 to 76°F) while relative humidity varied between 60 and 76 percent. Evaporated water remained below 80 percent which supports the data above (Table 20) that the minimum air flow rate to obtain maximum water removal had been exceeded.

The minimum air flow rate of 845 cm^3/sec (1.79 ft^3/min) used in this study evaporated 59 to 78 percent of the water in the manure during an accumulation time of 24 to 72 hours (Table 22). Even though the relative humidity was 54 percent, the 59 percent of evaporated water was less than that evaporated when accumulation time was longer and relative humidities were higher. These data continue to indicate the need to allow the manure to accumulate longer than 24 hours to obtain more water removal. Even at this low rate of air flow, substantial quantities of water were evaporated (Table 22).

The final test was to determine how much water could be evaporated with no blown air. Only the normal, or conventional, ventilation system was used. Temperature varied between 19 and 25°C (67 and 77°F) and relative humidity ranged between 64 and 68 percent (Table 23). However, evaporated water from the manure amounted to only 19 to 38 percent for the three accumulation periods, the maximum being 72 hours. With no air movement over the manure, less than one-half of the fecal water was evaporated as was achieved with the minimum air flow of 845 cm^3/sec (1.79 ft^3/min) per bird (Table 22). As in all of the other tests, less water was evaporated during the 24-hour accumulation period than in any of the other longer accumulation periods.

Water Added to the Ventilation Air

There were two main sources of water which added moisture to the ventilation air: respired moisture from the birds and water evaporated from the manure. A third source—evaporation from the water troughs—was omitted. The surface area of the water in the troughs was small in comparison to the surface area of the manure, and the flow was limited to 15 minutes each hour for 14 of the 24 hours.

The addition to the ventilation air of 80 percent or more of the water in the manure gave some concern about the effect it would have on humidity in the room. Subsequent analysis dispelled this concern.

The respired moisture was calculated from the latent heat produced by the birds. During warm weather the latent heat was less than one-half of the total heat produced by the birds.

At the maximum air flow rate of 1836 cm^3/sec (3.89 ft^3/min) per bird (Table 24), water removed by ventilation air ranged between 7.41 grams (114 grains) and 8.84 grams (136 grains) per hour. At no time did the amount of evaporated water from manure exceed the amount of water respired by the birds during accumulation periods of 24 to 144 hours. The temperature varied from 16°C (60°F) to 28°C (83°F). The 8°C (15°F) difference in room temperature affected the amount of latent heat produced by the birds which varied between 29-46 percent (Table 24).

At the air flow rate of 1671 cm^3/sec (3.54 ft^3/min) per bird the water removed by ventilation air ranged between 8.34 (129 grains) and 8.89 grams (137 grains) per hour (Table 25). The amount of water evaporated from manure did not exceed the amount of respired water. During the six manure accumulation periods of 24 to 144 hours, the room temperatures varied between 21°C (69°F) and 28°C (83°F). This was a difference of 7°C (14°F) which caused the latent heat to range between 33 and 46 percent of the total heat produced by the birds (Table 25).

When ventialtion air flow rate was reduced to 1473 cm^3/sec (3.12 ft^3/min) per bird, water removed from the building ranged between 9.21 grams (142 grains) and 7.85 grams (121 grains) per hour (Table 26). The amount of water evaporated from manure at no time exceeded the amount of respired moisture produced by the birds. During the six manure accumulation periods of 24 to 144 hours, the room temperature varied between 25°C (77°F) and 26°C (78°F). As a result of this relatively uniform temperature, the percent of latent heat also was nearly constant at about 41 percent (Table 26).

At the air flow rate of 1326 cm^3/sec (2.81 ft^3/min) per bird, water removed from the building ranged between 8.40 grams (130 grains) and 6.88 grams (106 grains) per hour

(Table 27). This air flow rate was not adequate to sustain moisture removal at the same levels as with higher air flow rates. The average was 7.66 grams (118 grains) per bird per hour. For higher air flow rates, water added to the ventilation air exceeded 8.00 grams (123 grains) per bird per hour. Again the amount of water evaporated from manure did not exceed the amount of respired moisture produced by the birds. The building temperature during the six manure accumulation periods of 24 to 144 hours ranged between 19°C (67°F) and 25°C (77°F). This difference of 6°C (10°F) resulted in a variation of 32 to 40 percent of the amount of the total heat that was latent heat produced by the birds (Table 27).

With air flow rate of 1071 cm^3/sec (2.27 ft^3/min), manure accumulation was limited to the 24, 48, and 72 hour periods for reasons expressed earlier (Table 28). Room temperature varied between 21°C (69°F) and 24°C (76°F) which caused the latent heat to vary between 33 and 39 percent of the total heat produced by the birds. Water added to the ventilation air varied between 7.66 (118) and 7.86 (121) grams (grains) per hour per bird. This was an average of 7.75 (120) grams (grains) per hour per bird for the three accumulation periods (Table 28). This average was slightly higher than for the previous test (Table 27) but still below the more than 8.00 (123) grams (grains) obtained with higher air flow rates.

Evaporation of water at the minimum air flow rate of 845 cm^3/sec (1.79 ft^3/min) added 6.85 (106) to 8.41 (130) grams (grains) per hour per bird to the ventilation air for the three accumulation periods (Table 29). The average was 7.68 (120) grams (grains). Room temperatures of 21°C (69°F) to 26°C (79°F) were slightly higher than for the previous tests which caused the latent heat to increase to 33-42 percent of the total heat. This simply increased the respired moisture added to the ventilation air and slightly decreased available sensible heat to evaporate water. At the higher room temperatures there was additional heat in the ventilation air to make up the difference, if it was needed (Table 29).

For the final test, no recirculated air was blown over the manure. Only the normal, or conventional, poultry house ventilation system was used. Thus the air movement over the manure was negligible compared with other tests in this study. Although temperatures ranged between 19°C (67°F) and 25°C (77°F), which were equivalent to the previous tests, only 5.62 (87) to 6.10 (94) grams (grains) of water per hour per bird were added to the ventilation air (Table 30).

Summary of Sensible Heat Used to Evaporate Water

A summary of sensible heat produced by birds to evaporate water from manure ranged from a low of 9 percent with no air flow to a maximum of 53 percent when the air flow was 1473 cm^3 (3.12 ft^3/min) per hour per bird (Table 31). Since there was no attempt to control temperature and relative humidity–only the rate of the incoming air–there were wide fluctuations, or variations, which affected water evaporation. Temperatures are listed to aid the reader when comparing percentages of heat used for the various rates of air flow and lengths of accumulation periods.

Additional analyses were made of these data to determine the average percent of sensible heat used and the average temperature for each of the five rates of air flow and for the zero air flow. These were for six accumulation periods for the four highest rates of air flow and three accumulation periods for the two lowest air flow rates and zero air flow (Table 31). At the highest rate of air flow, 39 percent of the available sensible heat was used while 45 percent was used for the next two highest rates of air flow. Average temperatures were 22°C (72°F), 25°C (77°F), and 25°C (77°F), respectively. At 22°C (72°F) more sensible heat was produced by the birds than at 25°C (77°F). Virtually the same quantity of water was evaporated per bird for these three air flow rates (see last column in Tables 24, 25, and 26). Thus, the lower percentage of sensible heat used was attributed to additional sensible heat available. (The increase in sensible heat in incoming air at the higher temperatures was not considered).

At the air flow rate of 1326 cm^3/sec (2.81 ft^3/min), the average temperature of 22°C (72°F) was the same as for the highest rate of air flow. This supports previous data that the minimum rate of air flow to obtain maximum evaporation was reached, perhaps exceeded, for warm weather operations.

Data for the two lowest rates of air flow and zero air flow were not recorded for the accumulation periods of 96, 120, and 144 hours. Thus, the heat-used averages cannot be compared with the averages for the four higher rates of air flow. It is obvious that with zero air flow utilization of available sensible heat to evaporate water was negligible (Table 31). For all of the tests, except one, less than 50 percent of the available sensible heat produced by the birds was used to evaporate water from the manure.

Summary of Percent Water Evaporated From The Manure

Water evaporated from the manure ranged between 88 and 52 percent for 30 tests in which air was blown over manure. For three tests when no air was blown, only 19 to 38 percent of the water was evaporated (Table 32). The highest level, or amount of evaporation, occurred when the air flow rate was 1473 cm^3/sec (3.12 ft^3/min) per bird or above. For 24 tests involved, water evaporation varied between 65 and 88 percent. The lowest evaporation rates occurred during 24-hour accumulation periods.

When the air flow rate was reduced below 1473 cm^3/sec (3.12 ft^3/min) per bird, it was no longer possible to obtain water evaporation at the 80 percent level or above. Water evaporation of 69 to 74 percent for three lower air flow rates was still exceptionally good when compared with 19 to 38 percent when no air was blown (Table 32).

The overall average of water evaporation for six

accumulation periods was about 80 percent, as long as the air flow rate was 1473 cm^3/sec (3.12 ft^3/min) per bird or above–a 64 percent reduction in manure weight at time of removal (Figure 3). More than 70 percent of the water was evaporated at the lower air flow rates.

With no air flowing over the manure, 38 percent of the water was evaporated during the 72-hour accumulation period, which reduced the weight to 29 percent at the time of removal.

Summary of Hourly Evaporated Water Added to the Ventilation Air

Usually air flow rates are given in cm^3/sec (ft^3/min) while heat and moisture production by the birds are presented in kcal (Btu) per hour. Thus, data in the summary of evaporated water added to ventilation (exhaust) air are presented in grams (grains) per hour per bird housed (Table 33). The maximum amount of 4.31 grams (67 grains) added to ventilation air occurred during the 72-hour accumulation period and an air flow rate of 1836 cm^3/sec (3.89 ft^3/min). During the same rate of air flow the amount of water evaporated dropped to 2.56 grams (grains) per bird housed for the 96-hour accumulation period. This was primarily due to high relative humidity of 73 percent which prevailed during this particular test (Table 32). The lowest evaporation of 0.66 grams (10 grains) per bird housed occurred during the 24-hour accumulation period when no air was blown.

An average of 3.40 grams (52 grains) of water was evaporated from the manure for six accumulation periods for the three highest air flow rates. For the lower three air flow rates, an average 2.79 grams (43 grains) of water was evaporated per bird. When no air was blown, an average of 1.05 grams (16 grains) was evaporated per bird.

Summary of Evaporated Water Added to Exhaust Air

This summary is for 33 tests which involved seven rates of exhaust air flow of 0.166 m^3/sec (351 ft^3/min) to 0.219 m^3/sec (464 ft^3/min) and six manure accumulation periods of 24 to 144 hours (Table 34). Water evaporated from the manure was removed from the room in exhaust air. Weight of evaporated water in the exhaust air is presented in grams/kg (grains/lb) of air for each of the tests (Table 34). This is a convenient means for determining water in air when using psychrometric tables or graphs.

The 24-hour accumulation time for manure simply was not long enough to achieve maximum water evaporation (Table 33). This applied to all rates of air flow, except the maximum rate used.

As long as the average relative humidity remained below 70 percent (Table 32), the evaporation rate was at or above 0.571 grams/kg (4.00 grains/lb) of air for the three highest air flow rates and manure accumulation periods of 48 to 144 hours (Table 34). When the air flow rate was reduced below 0.180 m^3/sec (380 ft^3/min), it was no longer possible to maintain the same level of evaporation. At the three lower rates of air flow the evaporation of water was far better than with no air at all.

The average quantity of water removed from the manure for six accumulation periods was virtually the same for the first three (highest) rates of air flow. The difference was 0.035 grams/kg (0.10 grains/lb) of air.

The maximum evaporation of 0.647 grams/kg (4.53 grains/lb) of air occurred during the 72-hour accumulation period and an air flow rate of 0.172 m^3/sec (365 ft^3/min). The temperature was 20°C (69°F) and relative humidity was 63 percent (Table 32). Under these conditions, evaporated water increased the relative humidity of the exhaust air by approximately five percent (estimated from the psychrometric chart).

CONCLUSIONS

To accomplish the warm weather partial in-house drying of manure, a blower was coupled to an air duct system installed between two rows of cages, three tiers high, to blow air at six different rates over the manure. Another blower was used to exhaust air from the room. Normally only the blowers, or fans, used for ventilation would be needed. To do so, would require the redesign of the conventional poultry house ventilation system so that all of the air was forced through the duct system between the cages.

Blowing air over manure as it accumulated on conveyor belts under the cages evaporated approximately 80 percent of the water when the average relative humidity was under 70 percent and the air flow rate was equivalent to 472 cm^3/sec (1 ft^3/min) per pound of bird. Thus the weight of manure was reduced 64 percent at time of removal. In the drier condition, it was much easier to handle and had appreciably less odors. In fact, there were virtually no ammonia odors or flies.

Sensible heat to evaporate water from manure came from two sources–from the incoming, or ventilation air, and the birds. Only heat from the birds was used in the analysis of data. The principal reason for using bird heat was to determine how much, if any, remained to provide heat for the room during cooler weather. As the data will show, less than 50 percent of the sensible heat produced by birds was used to evaporate water from manure.

Initially, there was some concern as to the effect the evaporation of 80 percent of the water from the manure would have on relative humidity in the room. Analyses show that respired moisture from the bird by far exceeded the evaporated moisture from manure. On the average, water evaporated from the manure increased the relative humidity of exhaust air five percent or less.

Some of the advantages of in-house drying of the manure, the air duct system between the cages, and the conveyor belt for removing the manure are: (1) reduced weight and improved handling characteristics of manure; (2) use of sensible heat which would otherwise be wasted; (3) slightly lowered room temperature by the conversion of sensible heat to latent heat during the evaporation process;

(4) fresh air for all of the birds; (5) vertically tiered cages increased bird density; (6) near elimination of odors, especially ammonia, and flies which improved the room environment for birds and operator; and (7) completely mechanized system for removing manure.

TABLE 1
TOTAL AND PER BIRD AIR FLOW RATES

Orifice Dia.	Chamber Air Flow Total	Recirculated	Exhausted	Air Flow Per Bird* Total	Recirculated	Exhausted
cm (in)	m^3/sec (ft^3/min)	m^3/sec (ft^3/min)	m^3/sec (ft^3/min)	cm^3/sec (ft^3/min)	cm^3/sec (ft^3/min)	cm^3/sec (ft^3/min)
--	0.2190 (464)	--	0.2190 (464)	1520 (3.22)	--	1520 (3.22)
7.62 (3)	0.3163 (670)	0.1218 (258)	0.1945 (412)	2195 (4.65)	845 (1.79)	1350 (2.86)
10.16 (4)	0.3445 (730)	0.1543 (327)	0.1902 (403)	2393 (5.07)	1071 (2.27)	1322 (2.80)
12.70 (5)	0.3743 (793)	0.1912 (405)	0.1831 (388)	2600 (5.51)	1326 (2.81)	1274 (2.70)
15.24 (6)	0.3913 (829)	0.2119 (449)	0.1794 (380)	2719 (5.76)	1473 (3.12)	1246 (2.64)
20.32 (8)	0.4130 (875)	0.2407 (510)	0.1723 (365)	2870 (6.08)	1671 (3.54)	1199 (2.54)
25.40 (10)	0.4300 (911)	0.2643 (560)	0.1657 (351)	2988 (6.33)	1836 (3.89)	1152 (2.44)

*Based on cage capacity of 144 laying hens.

TABLE 2

Weight and Percent Water Content
of Fresh Manure for 100 Laying Hens

	Two-Hour Intervals				Accumulation			
	Young Hens (2)		Old Hens (3)		Young Hens (2)		Old Hens (3)	
Time (1) (Hours)	Fresh Weight	Water Content	Fresh Weight	Water Content	Fresh Weight	Water Content	Fresh Weight	Water Content
	kg (lb)	%	kg (lb)	%	kg (lb)	%	kg (lb)	%
8-10 A.M.	2.402 (5.28)	85.22	1.913 (4.21)	82.72	2.402 (5.28)	85.22	1.913 (4.21)	82.72
10-12 A.M.	1.452 (3.19)	81.36	1.767 (3.89)	81.38	3.854 (8.48)	83.77	3.680 (8.10)	82.07
12-2 P.M.	1.523 (3.35)	83.06	1.550 (3.41)	79.30	5.377 (11.83)	83.57	5.230 (11.51)	81.24
2-4 P.M.	1.413 (3.11)	81.89	1.431 (3.15)	79.14	6.790 (14.94)	83.22	6.661 (14.65)	80.80
4-6 P.M.	1.343 (2.96)	81.96	1.410 (3.10)	78.95	8.133 (17.89)	83.01	8.072 (17.76)	80.48
6-8 P.M.	1.298 (2.86)	79.58	1.370 (3.01)	78.65	9.431 (20.75)	82.54	9.442 (20.77)	80.22
8-10 P.M.	1.134 (2.49)	79.21	1.331 (2.93)	78.47	10.565 (23.24)	82.18	10.773 (23.70)	80.01
10-12 P.M.	0.766 (1.69)	76.64	0.343 (0.76)	78.01	11.331 (24.93)	81.80	11.116 (24.46)	79.94
12-2 A.M.	0.706 (1.55)	79.34	0.683 (1.50)	79.79	12.038 (26.48)	81.66	11.799 (25.96)	79.93
2-4 A.M.	0.868 (1.91)	81.40	0.733 (1.61)	79.83	12.196 (28.39)	81.64	12.532 (27.57)	79.92
4-6 A.M.	0.783 (1.72)	81.95	0.800 (1.76)	79.88	13.689 (30.12)	81.66	13.332 (29.33)	79.86
6-8 A.M.	0.920 (2.02)	81.87	1.177 (2.59)	80.08	14.691 (32.32)	81.77	14.509 (31.92)	79.94

(1) Lights on from 8 A.M. to 10 P.M.
(2) Young Hens, July 20, 1973
(3) Old Hens, Oct. 20, 1974

TABLE 3

Weight and Percent of Water Evaporated From 100 Kilograms or Pounds of Material as Water Content is Reduced From 80 to 10 Percent (Wet Basis)

Total Weight (kg or lb)	Water Content (%)	Water Content (kg or lb)	Water Evaporated* (kg or lb)	Water Evaporated (%)
100.00	80	80.00	0	0
80.00	75	60.00	20.00	25.00
66.67	70	46.67	33.33	41.67
57.14	65	37.14	42.86	53.58
50.00	60	30.00	50.00	62.50
44.44	55	24.44	55.56	69.45
40.00	50	20.00	60.00	75.00
36.36	45	16.36	63.64	80.00
33.33	40	13.33	66.67	83.34
30.77	35	10.77	69.23	86.54
28.57	30	8.57	71.43	89.29
26.67	25	6.67	73.33	91.66
25.00	20	5.00	75.00	93.75
23.53	15	3.53	76.47	95.59
22.22	10	2.22	77.78	97.23

*The weight of water evaporated is also the percent of weight reduction of the material.

TABLE 4

Evaporation of Water From Manure As It Accumulated for Twenty-Four Hours Using Recirculated In-House Air at Different Rates of Flow.

Recirculated Air	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Evaporation Water	
			Total	Water	Total	Water	Water			
cm^3/sec (ft^3/min)	°C (°F)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
1836 (3.89)	20 (68)	60	16.95 (37.29)	13.56 (29.83)	6.73 (14.81)	3.34 (7.35)	50	3.39 (7.46)	10.22 (22.48)	75
1671 (3.54)	26 (79)	58	14.80 (32.56)	11.84 (26.05)	6.31 (13.88)	3.35 (7.37)	53	2.96 (6.51)	8.49 (18.68)	72
1473 (3.12)	26 (79)	67	17.15 (37.73)	13.72 (30.18)	8.19 (18.02)	4.76 (10.47)	58	3.43 (7.55)	8.96 (19.71)	65
1326 (2.81)	22 (72)	77	17.25 (37.95)	13.80 (30.36)	10.14 (22.31)	6.69 (14.72)	66	3.45 (7.59)	7.11 (15.64)	52
1071 (2.27)	24 (76)	60	17.05 (37.51)	13.64 (30.01)	7.90 (17.38)	4.49 (9.88)	57	3.41 (7.50)	9.15 (20.13)	67
845 (1.79)	21 (69)	54	16.05 (35.31)	12.84 (28.25)	8.41 (18.50)	5.20 (11.44)	62	3.21 (7.06)	7.64 (16.81)	59
0	25 (77)	68	14.95 (32.89)	11.96 (26.31)	12.69 (27.92)	9.70 (21.34)	76	2.99 (6.58)	2.26 (4.97)	19

(1) Based on full capacity of 144 birds
(2) Quantity of fresh manure calculated from dry manure and 80 per cent moisture

TABLE 5

Evaporation of Water From Manure As It Accumulated for Forty-Eight Hours Using Recirculated In-House Air at Different Rates of Flow.

Recirculated Air	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Evaporation Water	
			Total	Water	Total	Water	Water			
cm^3/sec (ft^3/min)	°C (°F)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
1836 (3.89)	16 (60)	58	32.15 (70.73)	25.72 (56.58)	11.72 (25.78)	5.29 (11.64)	45	6.43 (14.15)	20.43 (44.95)	79
1671 (3.54)	22 (72)	48	32.20 (70.84)	25.76 (56.67)	9.46 (20.81)	3.02 (6.64)	32	6.44 (14.17)	22.74 (50.03)	88
1473 (3.12)	25 (77)	57	35.55 (78.21)	28.44 (62.57)	12.85 (28.27)	5.74 (12.63)	45	7.11 (15.64)	22.70 (49.94)	80
1326 (2.81)	19 (67)	49	26.70 (58.74)	21.36 (49.99)	10.21 (22.46)	4.87 (10.71)	48	5.34 (11.75)	16.49 (36.28)	77
1071 (2.27)	22 (72)	64	34.80 (76.56)	27.84 (61.25)	13.50 (29.70)	6.54 (14.39)	48	6.96 (15.31)	21.30 (46.86)	77
845 (1.79)	25 (77)	62	32.00 (70.40)	25.60 (56.32)	13.91 (30.60)	7.51 (16.52)	54	6.40 (14.08)	18.09 (39.80)	71
0	19 (67)	66	33.25 (73.15)	26.60 (58.52)	25.74 (56.63)	19.09 (42.00)	74	6.65 (14.63)	7.51 (16.52)	28

(1) Based on full capacity of 144 birds
(2) Quantity of fresh manure calculated from dry manure and 80 per cent moisture

TABLE 6

Evaporation of Water From Manure As It Accumulated for Seventy-Two Hours Using Recirculated In-house Air at Different Rates of Flow.

Recirculated Air	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Evaporation Water	
			Total	Water	Total	Water	Water			
cm^3/sec (ft^3/min)	°C (°F)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
1836 (3.89)	19 (67)	61	52.35 (115.17)	41.88 (92.14)	16.62 (36.56)	6.15 (13.53)	37	10.47 (23.02)	35.73 (78.61)	85
1671 (3.54)	21 (69)	63	52.55 (115.61)	42.04 (92.49)	17.75 (39.05)	7.28 (16.02)	41	10.51 (23.12)	34.76 (76.47)	83
1473 (3.12)	25 (77)	66	52.00 (114.40)	41.60 (91.52)	18.79 (41.34)	8.46 (18.61)	45	10.40 (22.88)	33.14 (72.91)	80
1326 (2.81)	20 (68)	58	45.30 (99.66)	36.24 (79.73)	16.53 (36.37)	7.44 (16.37)	45	9.06 (19.93)	28.80 (63.36)	79
1071 (2.27)	21 (69)	76	54.65 (120.23)	43.72 (96.18)	23.05 (50.71)	12.22 (26.88)	53	10.93 (24.05)	31.50 (69.30)	72
845 (1.79)	26 (79)	63	51.90 (114.18)	41.52 (91.34)	19.73 (43.41)	9.27 (20.39)	47	10.38 (22.84)	32.25 (70.95)	78
0	22 (71)	64	47.45 (104.39)	37.96 (83.51)	33.19 (73.02)	23.56 (51.83)	71	9.49 (20.88)	14.40 (31.68)	38

(1) Based on full capacity of 144 birds
(2) Quantity of fresh manure calculated from dry manure and 80 per cent moisture

TABLE 7

Evaporation of Water From Manure As It Accumulated for Ninety-Six Hours Using Recirculated In-House Air at Different Rates of Flow.

Recirculated Air	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Evaporation Water	
			Total	Water	Total	Water	Water			
cm^3/sec (ft^3/min)	^oC (^oF)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
1836 (3.89)	23 (73)	73	57.45 (126.39)	45.96 (101.11)	22.10 (48.62)	10.61 (23.34)	48	11.49 (25.28)	35.35 (77.77)	77
1671 (3.54)	28 (83)	62	61.30 (134.86)	49.04 (107.89)	20.27 (44.59)	8.11 (17.84)	40	12.26 (26.97)	40.93 (90.05)	83
1473 (3.12)	26 (79)	63	66.30 (145.86)	53.04 (116.69)	22.93 (50.45)	9.63 (21.19)	42	13.26 (29.17)	43.41 (95.50)	82
1326 (2.81)	25 (77)	62	71.05 (156.31)	56.84 (125.05)	27.43 (60.35)	13.17 (28.97)	48	14.21 (31.26)	43.67 (96.07)	77

TABLE 8

Evaporation of Water From Manure As It Accumulated for One Hundred Twenty Hours Using Recirculated In-House Air at Different Rates of Flow.

Recirculated Air	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Evaporation Water	
			Total	Water	Total	Water	Water			
cm^3/sec (ft^3/min)	^oC (^oF)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
1836 (3.89)	28 (83)	62	78.10 (171.82)	62.48 (137.46)	25.17 (55.37)	9.56 (21.03)	38	15.62 (34.36)	52.92 (116.42)	85
1671 (3.54)	26 (79)	60	82.05 (180.51)	65.64 (144.41)	25.27 (55.59)	8.84 (19.45)	35	16.41 (36.10)	56.80 (124.96)	87
1473 (3.12)	26 (79)	63	89.15 (196.13)	71.32 (156.90)	30.14 (66.31)	12.36 (27.19)	41	17.83 (39.23)	58.96 (129.71)	83
1326 (2.81)	24 (76)	73	88.70 (195.14)	70.96 (156.11)	34.10 (75.02)	16.37 (36.01)	48	17.74 (39.03)	54.59 (120.10)	77

TABLE 9

Evaporation of Water From Manure As It Accumulated for One Hundred Forty-four Hours Using Recirculated In-House Air at Different Rates of Flow.

Recirculated Air	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Evaporation Water	
			Total	Water	Total	Water	Water			
cm^3/sec (ft^3/min)	^oC (^oF)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
1836 (3.89)	23 (73)	65	90.50 (199.10)	72.40 (159.28)	29.28 (64.42)	11.13 (24.49)	38	18.10 (39.82)	61.27 (134.79)	85
1671 (3.54)	26 (79)	59	105.10 (231.22)	84.08 (184.98)	37.65 (82.83)	16.57 (36.45)	44	21.02 (46.24)	67.51 (148.52)	81
1473 (3.12)	26 (79)	66	105.55 (232.21)	84.44 (185.77)	37.43 (82.35)	16.47 (36.23)	44	21.11 (46.44)	67.97 (149.53)	81
1326 (2.81)	24 (76)	73	100.90 (221.98)	80.72 (177.58)	37.10 (81.62)	17.07 (37.55)	46	20.18 (44.40)	63.65 (140.03)	79

TABLE 10

Percent of Sensible Heat Produced Per Hour by the Birds
Used to Evaporate Water from the Manure When the
Recirculated Air Flow was 1836 cm^3/sec (3.89 ft^3/min) Per Bird

Hours (days)	Birds(1)	Temp	Heat(2) Produced	Total Bird Weight	Total Heat	Sensible Heat	Sensible Heat	Water Evaporated	Heat Used for Vaporation(3)	Sensible Heat Used
	number	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	kg (lbs)	kcal (btu)	%
24 (1)	115	20 (68)	4.92 (8.85)	201 (443)	988 (3921)	67	662 (2627)	0.426 (0.937)	260 (1031)	39
48 (2)	115	16 (60)	5.00 (9.00)	201 (443)	1005 (3987)	71	713 (2829)	0.426 (0.937)	260 (1031)	36
72 (3)	115	19 (67)	4.94 (8.90)	201 (443)	994 (3943)	68	676 (2681)	0.496 (1.092)	303 (1201)	45
96 (4)	144	23 (73)	4.72 (8.50)	252 (554)	1187 (4709)	64	759 (3014)	0.368 (0.810)	225 (891)	30
120 (5)	144	28 (83)	4.17 (7.50)	252 (554)	1047 (4155)	54	565 (2244)	0.441 (0.970)	269 (1067)	48
144 (6)	141	23 (73)	4.72 (8.50)	247 (543)	1163 (4616)	64	744 (2954)	0.426 (0.936)	259 (1030)	35

(1) Average bird weight 1.75 kg (3.85 lbs).
(2) USDA (Beltsville) calorimetric data, (Ota & McNally).
(3) Heat of Vaporization 611 kcal/kg (1100 btu/lbs).

TABLE 11

Percent of Sensible Heat Produced Per Hour by the Birds
Used to Evaporate Water from the Manure When the
Recirculated Air Flow was 1671 cm^3/sec (3.54 ft^3/min) Per Bird

Hours (days)	Birds(1)	Temp	Heat(2) Produced	Total Bird Weight	Total Heat	Sensible Heat	Sensible Heat	Water Evaporated	Heat Used for Vaporation(3)	Sensible Heat Used
	number	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	kg (lbs)	kcal (btu)	%
24 (1)	115	26 (79)	4.39 (7.90)	201 (443)	882 (3500)	58	512 (2030)	0.354 (0.778)	216 (856)	42
48 (2)	115	22 (72)	4.79 (8.60)	201 (443)	960 (3810)	65	624 (2477)	0.474 (1.042)	289 (1146)	46
72 (3)	115	21 (69)	4.89 (8.80)	201 (443)	982 (3898)	67	658 (2612)	0.483 (1.062)	295 (1168)	45
96 (4)	144	28 (83)	4.17 (7.50)	252 (554)	1047 (4155)	54	565 (2244)	0.426 (0.938)	260 (1032)	46
120 (5)	143	26 (79)	4.39 (7.90)	250 (551)	1097 (4353)	58	636 (2525)	0.473 (1.041)	289 (1145)	45
144 (6)	140	26 (79)	4.44 (8.00)	245 (539)	1087 (4312)	59	641 (2544)	0.469 (1.031)	286 (1134)	45

(1) Average bird weight 1.75 kg (3.85 lbs).
(2) USDA (Beltsville) calorimetric data, (Ota & McNally).
(3) Heat of Vaporization 611 kcal/kg (1100 btu/lb).

TABLE 12

Percent of Sensible Heat Produced Per Hour by the Birds
Used to Evaporate Water from the Manure when the
Recirculated Air Flow was 1473 cm^3/sec (3.12 ft^3/min) Per Bird

Hours (days)	Birds(1)	Temp	Heat(2) Produced	Total Bird Weight	Total Heat	Sensible Heat	Sensible Heat	Water Evaporated	Heat Used for Vaporation(3)	Sensible Heat Used
	number	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	kg (lbs)	kcal (btu)	%
24 (1)	144	26 (79)	4.39 (7.90)	252 (554)	1103 (4377)	58	640 (2539)	0.373 (0.821)	228 (903)	36
48 (2)	144	25 (77)	4.53 (8.10)	252 (554)	1131 (4487)	60	678 (2692)	0.473 (1.040)	289 (1144)	43
72 (3)	113	25 (77)	4.53 (8.10)	198 (435)	888 (3524)	60	533 (2114)	0.460 (1.013)	281 (1114)	53
96 (4)	143	26 (79)	4.39 (7.90)	250 (551)	1097 (4353)	58	636 (2525)	0.452 (0.995)	276 (1095)	43
120 (5)	139	26 (79)	4.39 (7.90)	243 (535)	1065 (4227)	58	618 (2452)	0.491 (1.081)	300 (1189)	49
144 (6)	139	26 (79)	4.44 (8.00)	243 (535)	1079 (4280)	59	636 (2525)	0.472 (1.038)	288 (1142)	45

(1) Average bird weight 1.75 kg (3.85 lbs).
(2) USDA (Beltsville) calorimetric data, (Ota & McNally).
(3) Heat of Vaporization 611 kcal/kg (1100 btu/lbs).

TABLE 13

Percent of Sensible Heat Produced Per Hour by the Birds Used to Evaporate Water from the Manure when the Recirculated Air Flow was 1326 cm^3/sec (2.81) Per Bird

Hours (days)	Birds(1)	Temp	Heat(2) Produced	Total Bird Weight	Total Heat	Sensible Heat	Sensible Heat	Water Evaporated	Heat Used for Vaporation(3)	Sensible Heat Used
	number	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	kg (lbs)	kcal (btu)	%
24 (1)	141	22 (72)	4.79 (8.60)	247 (543)	1177 (4670)	65	765 (3036)	0.296 (0.652)	181 (717)	24
48 (2)	141	19 (67)	4.94 (8.90)	247 (543)	1218 (4831)	68	828 (3285)	0.344 (0.756)	210 (832)	25
72 (3)	141	20 (68)	4.86 (8.85)	247 (543)	1211 (4806)	67	811 (3220)	0.400 (0.880)	240 (968)	30
96 (4)	139	25 (77)	4.53 (8.10)	243 (534)	1090 (4325)	60	654 (2595)	0.455 (1.001)	278 (1101)	42
120 (5)	139	24 (76)	4.56 (8.20)	243 (534)	1103 (4379)	61	673 (2671)	0.455 (1.001)	278 (1101)	41
144 (6)	138	24 (76)	4.56 (8.20)	242 (531)	1097 (4354)	61	669 (2656)	0.442 (0.972)	270 (1069)	40

(1) Average bird weight 1.75 kg (3.85 lbs).
(2) USDA (Beltsville) calorimetric data, (Ota & McNally).
(3) Heat of Vaporization 611 kcal/kg (1100 btu/lbs).

TABLE 14

Percent of Sensible Heat Produced Per Hour by the Birds
Used to Evaporate Water From the Manure When the
Recirculated Air Flow Was 1071 cm^3/sec (2.27 ft^3/min) Per Bird

Hours (days)	Birds (1)	Temp.	Heat (2) Produced	Total Bird Weight	Total Heat	Sensible Heat	Sensible Heat	Water Evaporated	Heat Used for Vaporation (3)	Sensible Heat Used
	number	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	kg (lbs)	kcal (btu)	%
24 (1)	144	24 (76)	4.56 (8.21)	252 (554)	1149 (4547)	61	701 (2774)	0.381 (0.839)	233 (923)	33
48 (2)	144	22 (72)	4.78 (8.60)	252 (554)	1205 (4764)	65	783 (3097)	0.444 (0.975)	271 (1073)	35
72 (3)	144	21 (69)	4.89 (8.80)	252 (554)	1232 (4875)	67	826 (3266)	0.438 (0.963)	268 (1059)	32

(1) Average bird weight 1.75 kg (3.85 lbs).
(2) USDA (Beltsville) calorimetric data, (Ota & McNally).
(3) Heat of Vaporization 611 kcal/kg (1100 btu/lbs).

TABLE 15

Percent of Sensible Heat Produced Per Hour by the Birds Used to Evaporate Water From the Manure When the Recirculated Air Flow Was 845 cm^3/sec (1.79 ft^3/min) Per Bird

Hours (days)	Birds (1)	Temp.	Heat (2) Produced	Total Bird Weight	Total Heat	Sensible Heat	Sensible Heat	Water Evaporated	Heat Used for Vaporation (3)	Sensible Heat Used
	number	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	kg (lbs)	kcal (btu)	%
24 (1)	143	21 (69)	4.89 (8.80)	250 (551)	1223 (4849)	67	819 (3249)	0.318 (0.700)	194 (770)	24
48 (2)	143	25 (77)	4.50 (8.10)	250 (551)	1125 (4463)	60	675 (2678)	0.377 (0.829)	230 (912)	34
72 (3)	143	26 (79)	4.39 (7.90)	250 (551)	1098 (4353)	58	637 (2525)	0.448 (0.985)	274 (1084)	43

(1) Average bird weight 1.75 kg (3.85 lbs).
(2) USDA (Beltsville) calorimetric data, (Ota & McNally).
(3) Heat of Vaporization 611 kcal/kg (1100 btu/lbs).

TABLE 16

Percent of Sensible Heat Produced Per Hour by the Birds
Used to Evaporate Water From the Manure When
There Is No Air Flow Over the Manure

Hours (days)	Birds (1)	Temp	Heat (2) Produced	Total Bird Weight	Total Heat	Sensible Heat	Sensible Heat	Water Evaporated	Heat Used for Vaporation (3)	Sensible Heat Used
	number	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	kg (lbs)	kcal (btu)	%
24 (1)	143	25 (77)	4.50 (8.10)	250 (551)	1125 (4463)	60	675 (2678)	0.094 (0.207)	57 (228)	9
48 (2)	143	19 (67)	4.94 (8.90)	250 (551)	1238 (4904)	68	842 (3335)	0.156 (0.344)	95 (378)	11
72 (3)	143	22 (71)	4.83 (8.70)	250 (551)	1208 (4794)	66	797 (3164)	0.200 (0.440)	122 (484)	15

(1) Average bird weight 1.75 kg (3.85 lbs).
(2) USDA (Beltsville) calorimetric data, (Ota & McNally).
(3) Heat of Vaporization 611 kcal/kg (1100 btu/lbs).

TABLE 17

Weight and Percent of Water Evaporated Out of the Manure As It Accumulated For 24 to 144 Hours With a Constant Air Flow of 1836 cm^3/sec (3.89 ft^3/min.) per Bird.

Hours (days)	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Evaporation	
			Total	Water	Total	Water	Water		Water	
	°C (°F)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
24 (1)	20 (68)	60	16.95 (37.29)	13.56 (29.83)	6.73 (14.81)	3.34 (7.35)	50	3.39 (7.46)	10.22 (22.48)	75
48 (2)	16 (60)	58	32.15 (70.73)	25.72 (56.58)	11.72 (25.78)	5.29 (11.64)	45	6.43 (14.15)	20.43 (44.95)	79
72 (3)	19 (67)	61	52.35 (115.17)	41.88 (92.14)	16.62 (36.56)	6.15 (13.53)	37	10.47 (23.03)	35.73 (78.61)	85
96 (4)	23 (73)	73	57.45 (126.39)	45.96 (101.11)	22.10 (48.62)	10.61 (23.34)	48	11.49 (25.28)	35.35 (77.77)	77
120 (5)	28 (83)	62	78.10 (171.82)	62.48 (137.46)	25.17 (55.37)	9.56 (21.03)	38	15.62 (34.36)	52.92 (116.42)	85
144 (6)	23 (73)	65	90.50 (199.10)	72.40 (159.28)	29.28 (64.42)	11.13 (24.49)	38	18.10 (39.82)	61.27 (134.79)	85

TABLE 18

Weight and Percent of Water Evaporated Out of the Manure As It Accumulated For 24 to 144 Hours With a Constant Air Flow of 1671 cm^3/sec (3.54 ft^3/min) per Bird

Hours (days)	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Water	Evaporation Water
			Total	Water	Total	Water	Water			
	°C (°F)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
24 (1)	26 (79)	58	14.80 (32.56)	11.84 (26.05)	6.31 (13.88)	3.35 (7.37)	53	2.96 (6.51)	8.49 (18.68)	72
48 (2)	22 (72)	48	32.20 (70.84)	25.76 (56.67)	9.46 (20.81)	3.02 (6.64)	32	6.44 (14.17)	22.74 (50.03)	88
72 (3)	21 (69)	63	52.55 (115.61)	42.04 (92.49)	17.75 (39.05)	7.28 (16.02)	41	10.51 (23.12)	34.76 (76.47)	83
96 (4)	28 (83)	62	61.30 (134.86)	49.04 (107.89)	20.27 (44.59)	8.11 (17.84)	40	12.26 (26.97)	40.93 (90.05)	83
120 (5)	26 (79)	60	82.05 (180.51)	65.64 (144.41)	25.27 (55.59)	8.84 (19.45)	35	16.41 (36.10)	56.80 (124.96)	87
144 (6)	26 (79)	59	105.10 (231.22)	84.08 (184.98)	37.65 (82.83)	16.57 (36.45)	44	21.02 (46.24)	67.51 (148.52)	81

TABLE 19

Weight and Percent of Water Evaporated Out of the Manure As It Accumulated
For 24 to 144 Hours With a Constant Air Flow of 1473 cm^3/sec (3.12 ft^3/min) per Bird

Hours (days)	Chamber Temperature °C (°F)	Chamber Rel. Hum. %	Fresh Manure Total kg (lbs)	Fresh Manure Water kg (lbs)	Manure Removed Total kg (lbs)	Manure Removed Water kg (lbs)	Manure Removed Water %	Dry Manure kg (lbs)	In-House Evaporation Water kg (lbs)	In-House Evaporation Water %
24 (1)	26 (79)	67	17.15 (37.73)	13.72 (30.18)	8.19 (18.02)	4.76 (10.47)	58	3.43 (7.55)	8.96 (19.71)	65
48 (2)	25 (77)	57	35.55 (78.21)	28.44 (62.57)	12.85 (28.27)	5.74 (12.63)	45	7.11 (15.64)	22.70 (49.94)	80
72 (3)	25 (77)	66	52.00 (114.40)	41.60 (91.52)	18.79 (41.34)	8.46 (18.61)	45	10.40 (22.88)	33.14 (72.91)	80
96 (4)	26 (79)	63	66.30 (145.86)	53.04 (116.69)	22.93 (50.45)	9.63 (21.19)	42	13.26 (29.17)	43.41 (95.50)	82
120 (5)	26 (79)	63	89.15 (196.13)	71.32 (156.90)	30.14 (66.31)	12.36 (27.19)	41	17.83 (39.23)	58.96 (129.71)	83
144 (6)	26 (79)	66	105.55 (232.21)	84.44 (185.77)	37.43 (82.35)	16.47 (36.23)	44	21.11 (46.44)	67.97 (149.53)	81

TABLE 20

Weight and Percent of Water Evaporated Out of the Manure As It Accumulated
For 24 to 144 Hours With a Constant Air Flow of 1326 cm^3/sec (2.81 ft^3/min) per Bird

Hours (days)	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Evaporation Water	Evaporation Water
			Total	Water	Total	Water	Water			
	°C (°F)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
24 (1)	22 (72)	77	17.25 (37.95)	13.80 (30.36)	10.14 (22.31)	6.69 (14.72)	66	3.45 (7.59)	7.11 (15.64)	52
48 (2)	19 (67)	49	26.70 (58.74)	21.36 (49.99)	10.21 (22.46)	4.87 (10.71)	48	5.34 (11.75)	16.49 (36.28)	77
72 (3)	20 (68)	58	45.30 (99.66)	36.24 (79.73)	16.53 (36.37)	7.44 (16.37)	45	9.06 (19.93)	28.80 (63.36)	79
96 (4)	25 (77)	62	71.05 (156.31)	56.84 (125.05)	27.43 (60.35)	13.17 (28.97)	48	14.21 (31.26)	43.67 (96.07)	77
120 (5)	24 (76)	73	88.70 (195.14)	70.96 (156.11)	34.10 (75.02)	16.37 (36.01)	48	17.74 (39.03)	54.59 (120.10)	77
144 (6)	24 (76)	73	100.90 (221.98)	80.72 (177.58)	37.10 (81.62)	17.07 (37.55)	46	20.18 (44.40)	63.65 (140.03)	79

TABLE 21

Weight and Percent of Water Evaporated Out of the Manure as it Accumulated
For 24 to 72 Hours with a Constant Air Flow of 1071 cm^3/sec (2.27 ft^3/min) Per Bird

Hours (days)	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Evaporation Water	
			Total	Water	Total	Water	Water		Water	
	°C (°F)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
24 (1)	24 (76)	60	17.05 (37.51)	13.64 (30.01)	7.90 (17.38)	4.49 (9.88)	57	3.41 (7.50)	9.15 (20.13)	67
48 (2)	22 (72)	64	34.80 (76.56)	27.84 (61.25)	13.50 (29.70)	6.54 (14.39)	48	6.96 (15.31)	21.30 (46.86)	77
72 (3)	21 (69)	76	54.65 (120.23)	43.72 (96.18)	23.05 (50.71)	12.22 (26.88)	53	10.93 (24.05)	31.50 (69.30)	72

TABLE 22

Weight and Percent of Water Evaporated Out of the Manure as it Accumulated For 24 to 72 Hours with a Constant Air Flow of 845 cm^3/sec (1.79 ft^3/min) Per Bird

Hours (days)	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Evaporation Water	
			Total	Water	Total	Water	Water		Water	
	°C (°F)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
24 (1)	21 (69)	54	16.05 (35.31)	12.84 (28.25)	8.41 (18.50)	5.20 (11.44)	62	3.21 (7.06)	7.64 (16.81)	59
48 (2)	25 (77)	62	32.00 (70.40)	25.60 (56.32)	13.91 (30.60)	7.51 (16.52)	54	6.40 (14.08)	18.09 (39.80)	71
72 (3)	26 (78)	63	51.90 (114.18)	41.52 (91.34)	19.73 (43.41)	9.27 (20.39)	47	10.38 (22.84)	32.25 (70.95)	78

TABLE 23

Weight and Percent of Water Evaporated Out of the Manure
As it Accumulated for 24 to 72 Hours with No Air Flow

Hours (days)	Chamber Temperature	Chamber Rel. Hum.	Fresh Manure		Manure Removed			Dry Manure	In-House Water	Evaporation Water
			Total	Water	Total	Water	Water			
	°C (°F)	%	kg (lbs)	kg (lbs)	kg (lbs)	kg (lbs)	%	kg (lbs)	kg (lbs)	%
24 (1)	25 (77)	68	14.95 (32.89)	11.96 (26.31)	12.69 (27.92)	9.70 (21.34)	76	2.99 (6.58)	2.26 (4.97)	19
48 (2)	19 (67)	66	33.25 (73.15)	26.60 (58.52)	25.74 (56.63)	19.09 (42.00)	74	6.65 (14.63)	7.51 (16.52)	28
76 (3)	22 (71)	64	47.45 (104.39)	37.96 (83.51)	33.19 (73.02)	23.56 (51.83)	71	9.49 (20.88)	14.40 (31.68)	38

TABLE 24

Average Hourly Respired and Evaporated Water Added to the Ventilation Air When the Recirculated Air Flow Was 1836 cm^3/sec (3.89 ft^3/min) Per Bird

Hours (days)	Birds (1)	Temp.	Heat (2) Produced	Total Bird Wt.	Total Heat	Latent Heat	Latent Heat	Water			Per Bird Housed
								Respired	Evaporated	Total	
	No.	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	grams (grains)	grams (grains)	grams (grains)	grams (grains)
24 (1)	115	20 (68)	4.92 (8.75)	201 (443)	988 (3921)	33	326 (1294)	534 (8234)	425 (6559)	958 (14,793)	8.34 (129)
48 (2)	115	16 (60)	5.00 (9.00)	201 (443)	1005 (3987)	29	291 (1156)	477 (7356)	425 (6559)	902 (13,915)	7.84 (121)
72 (3)	115	19 (67)	4.94 (8.90)	201 (443)	994 (3943)	32	318 (1262)	520 (8031)	496 (7654)	1016 (15,685)	8.84 (136)
96 (4)	144	23 (73)	4.72 (8.50)	252 (554)	1187 (4709)	36	427 (1696)	699 (10,793)	368 (5680)	1067 (16,473)	7.41 (114)
120 (5)	144	28 (83)	4.17 (7.50)	252 (554)	1047 (4155)	46	482 (1911)	788 (12,161)	441 (6806)	1229 (18,967)	8.53 (132)
144 (6)	141	23 (73)	4.72 (8.50)	247 (543)	1163 (4616)	36	419 (1662)	685 (10,576)	426 (6574)	1111 (17,150)	7.88 (122)

(1) Average bird weight 1.75 kg (3.85 lb).
(2) USDA (Beltsville) Calorimetric Data (Ota & McNally).

TABLE 25

Average Hourly Respired and Evaporated Water Added to the Ventilation Air When the Recirculated Air Flow Was 1671 cm^3/sec (3.54 ft^3/min) Per Bird

Hours (days)	Birds (1)	Temp.	Heat (2) Produced	Total Bird Wt.	Total Heat	Latent Heat	Latent Heat	Water			Per Bird Housed
								Respired	Evaporated	Total	
	No.	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	grams (grains)	grams (grains)	grams (grains)	grams (grains)
24 (1)	115	26 (79)	4.39 (7.90)	201 (443)	882 (3500)	42	370 (1470)	606 (9355)	353 (5448)	959 (14,803)	8.34 (129)
48 (2)	115	22 (72)	4.79 (8.60)	201 (443)	960 (3810)	35	336 (1334)	550 (8489)	473 (7296)	1023 (15,785)	8.89 (137)
72 (3)	115	21 (69)	4.89 (8.80)	201 (443)	982 (3898)	33	324 (1286)	530 (8186)	482 (7435)	1012 (15,621)	8.80 (136)
96 (4)	144	28 (83)	4.17 (7.50)	252 (554)	1047 (4155)	46	482 (1911)	788 (12,161)	425 (6566)	1213 (18,727)	8.42 (130)
120 (5)	143	26 (79)	4.39 (7.90)	250 (551)	1097 (4353)	42	461 (1828)	754 (11,634)	472 (7289)	1236 (18,923)	8.58 (132)
144 (6)	140	26 (79)	4.44 (8.00)	245 (539)	1087 (4312)	41	445 (1768)	729 (11,251)	468 (7220)	1197 (18,471)	8.55 (132)

(1) Average bird weight 1.75 kg (3.85 lb).
(2) USDA (Beltsville) Calorimetric Data (Ota & McNally).

TABLE 26

Average Hourly Respired and Evaporated Water Added to the Ventilation Air When the Recirculated Air Flow Was 1473 cm^3/sec (3.12 ft^3/min) Per Bird

Hours (days)	Birds (1)	Temp.	Heat (2) Produced	Total Bird Wt.	Total Heat	Latent Heat	Latent Heat	Water			Per Bird Housed
								Respired	Evaporated	Total	
	No.	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	grams (grains)	grams (grains)	grams (grains)	grams (grains)
24 (1)	144	26 (79)	4.39 (7.90)	252 (554)	1103 (4377)	42	463 (1838)	758 (11,699)	373 (5749)	1131 (17,448)	7.85 (121)
48 (2)	144	25 (77)	4.53 (8.10)	252 (554)	1131 (4487)	40	452 (1795)	740 (11,421)	472 (7283)	1212 (18,704)	8.42 (130)
72 (3)	113	25 (77)	4.53 (8.10)	198 (435)	888 (3524)	40	355 (1410)	581 (8973)	459 (7088)	1040 (16,061)	9.21 (142)
96 (4)	143	26 (79)	4.39 (7.90)	250 (551)	1097 (4353)	42	461 (1828)	754 (11,634)	451 (6964)	1205 (18,598)	8.43 (130)
120 (5)	139	26 (79)	4.39 (7.90)	243 (535)	1065 (4227)	42	447 (1775)	732 (11,298)	490 (7566)	1222 (18,864)	8.79 (136)
144 (6)	139	26 (79)	4.44 (8.00)	243 (535)	1079 (4280)	41	442 (1755)	724 (11,167)	471 (7269)	1195 (18,436)	8.59 (133)

(1) Average bird weight 1.75 kg (3.85 lb).
(2) USDA (Beltsville) Calorimetric Data (Ota & McNally).

TABLE 27

Average Hourly Respired and Evaporated Water Added to the Ventilation Air When the Recirculated Air Flow Was 1326 cm^3/sec (2.81 ft^3/min) Per Bird

Hours (days)	Birds (1)	Temp.	Heat (2) Produced	Total Bird Wt.	Total Heat	Latent Heat	Latent Heat	Water			Per Bird Housed
								Respired	Evaporated	Total	
	No.	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	grams (grains)	grams (grains)	grams (grains)	grams (grains)
24 (1)	141	22 (72)	4.79 (8.60)	247 (543)	1177 (4670)	35	412 (1634)	674 (10,398)	296 (4564)	970 (14,962)	6.88 (106)
48 (2)	141	19 (67)	4.94 (8.90)	247 (543)	1218 (4831)	32	390 (1546)	637 (9838)	343 (5292)	980 (15,130)	6.95 (107)
72 (3)	141	20 (68)	4.86 (8.85)	247 (543)	1211 (4806)	33	400 (1586)	654 (10,093)	351 (5421)	1005 (15,514)	7.13 (110)
96 (4)	139	25 (77)	4.53 (8.10)	243 (534)	1090 (4325)	40	436 (1730)	713 (11,009)	454 (7007)	1167 (18,016)	8.40 (130)
120 (5)	139	24 (76)	4.56 (8.20)	243 (534)	1103 (4379)	39	430 (1708)	704 (10,870)	454 (7007)	1158 (17,877)	8.33 (129)
144 (6)	138	24 (76)	4.56 (8.20)	242 (531)	1097 (4354)	39	428 (1698)	700 (10,805)	441 (6804)	1141 (17,609)	8.27 (128)

(1) Average bird weight 1.75 kg (3.85 lb).
(2) USDA (Beltsville) Calorimetric Data (Ota & McNally).

TABLE 28

Average Hourly Respired and Evaporated Water Added to the Ventilation Air When the Recirculated Air Flow Was 1071 cm^3/sec (2.27 ft^3/min) Per Bird

Hours (days)	Birds (1)	Temp.	Heat (2) Produced	Total Bird Wt.	Total Heat	Latent Heat	Latent Heat	Water			Per Bird Housed
								Respired	Evaporated	Total	
	No.	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	grams (grains)	grams (grains)	grams (grains)	grams (grains)
24 (1)	144	24 (76)	4.56 (18.21)	252 (554)	1149 (4547)	39	448 (1778)	733 (11,315)	381 (5880)	1114 (17,195)	7.74 (119)
48 (2)	144	22 (72)	4.78 (8.60)	252 (554)	1205 (4764)	35	422 (1667)	690 (10,611)	444 (6852)	1134 (17,463)	7.86 (121)
72 (3)	144	21 (69)	4.89 (8.80)	252 (554)	1232 (4875)	33	407 (1609)	665 (10,238)	438 (6759)	1103 (16,997)	7.66 (118)

(1) Average Bird Weight 1.75 kg (3.85 lb).
(2) USDA (Beltsville) Calorimetric Data (Ota & McNally).

TABLE 29

Average Hourly Respired and Evaporated Water Added to the Ventilation Air When the Recirculated Air Flow Was 845 cm^3/sec (1.79 ft^3/min) Per Bird

Hours (days)	Birds (1)	Temp	Heat (2) Produced	Total Bird Wt.	Total Heat	Latent Heat	Latent Heat	Water			Per Bird Housed
								Respired	Evaporated	Total	
	No.	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	grams (grains)	grams (grains)	grams (grains)	grams (grains)
24 (1)	143	21 (69)	4.89 (8.80)	250 (551)	1223 (4849)	33	404 (1600)	661 (10,183)	318 (4907)	979 (15,090)	6.85 (106)
48 (2)	143	25 (77)	4.50 (8.10)	250 (551)	1125 (4463)	40	450 (1785)	736 (11,360)	377 (5818)	1113 (17,178)	7.78 (120)
72 (3)	143	26 (79)	4.39 (7.90)	250 (551)	1098 (4353)	42	461 (1830)	755 (11,651)	448 (6914)	1203 (18,565)	8.41 (130)

(1) Average Bird Weight 1.75 kg (3.85 lb).
(2) USDA (Beltsville) Calorimetric Data (Ota & McNally).

TABLE 30

Average Hourly Respired and Evaporated Water Added to the Ventilation Air When There Is No Air Flow Over the Manure

Hours (days)	Birds (1)	Temp.	Heat (2) Produced	Total Bird Wt.	Total Heat	Latent Heat	Latent Heat	Water			Per Bird Housed
								Respired	Evaporated	Total	
	No.	°C (°F)	kcal/kg (btu/lb)	kg (lbs)	kcal (btu)	%	kcal (btu)	grams (grains)	grams (grains)	grams (grains)	grams (grains)
24 (1)	143	25 (77)	4.50 (8.10)	250 (551)	1125 (4463)	40	450 (1785)	736 (11360)	94 (1451)	830 (12811)	5.80 (90)
48 (2)	143	19 (67)	4.94 (8.90)	250 (551)	1238 (4904)	32	396 (1569)	648 (9986)	156 (2407)	804 (12393)	5.62 (87)
72 (3)	143	22 (71)	4.83 (8.70)	250 (551)	1208 (4794)	34	411 (1630)	672 (10372)	200 (3086)	872 (13458)	6.10 (94)

(1) Average Bird Weight 1.75 kg (3.85 lb).
(2) USDA (Beltsville) Calorimetric Data (Ota & McNally).

Summary
of

Percent of Sensible Heat Produced by the Birds Used to Evaporate Water From The Manure During Different Rates of Recirculated Air Flow and Accumulation Time

Hours (days)	Air Flow - cm^3/sec (ft^3/min) 1836 (3.89)	1671 (3.54)	1473 (3.12)	1326 (2.81)	1071 (2.27)	845 (1.79)	0 (0)
	Percent (Temperature - °C) (Temperature - °F)						
24 (1)	39 (20) (69)	42 (26) (79)	36 (26) (79)	24 (22) (72)	33 (24) (76)	24 (21) (69)	9 (25) (77)
48 (2)	36 (16) (60)	46 (22) (72)	43 (25) (77)	25 (19) (67)	35 (22) (72)	34 (25) (77)	11 (19) (67)
72 (3)	45 (19) (67)	45 (21) (69)	53 (25) (77)	30 (20) (68)	32 (21) (69)	43 (26) (79)	15 (22) (71)
96 (4)	30 (23) (73)	46 (28) (83)	43 (26) (79)	42 (25) (77)	--	--	--
120 (5)	48 (28) (83)	45 (26) (79)	49 (26) (79)	41 (24) (76)	--	--	--
144 (6)	35 (23) (73)	45 (26) (79)	45 (26) (79)	40 (24) (76)	--	--	--
Average	39 (22) (72)	45 (25) (77)	45 (26) (79)	34 (22) (72)	33 (22) (72)	34 (24) (76)	12 (22) (72)

TABLE 32
Summary
of
Percent of Water Evaporated From the Manure During
Different Rates of Air Flow and Accumulation Time*

Hours (days)	1836 (3.89)	1671 (3.54)	1473 (3.12)	1326 (2.81)	1071 (2.27)	845 (1.79)	0
	cm^3/sec (ft^3/min) per Bird						
	Percent (Temperature - °C) (Relative Humidity - %) (Temperature - °F)						
24 (1)	75 (20) (60) (68)	72 (26) (58) (79)	65 (26) (67) (79)	52 (22) (77) (72)	67 (24) (60) (76)	59 (21) (54) (69)	19 (25) (68) (77)
48 (2)	79 (16) (58) (60)	88 (22) (48) (72)	80 (25) (57) (77)	77 (19) (49) (67)	77 (22) (64) (72)	71 (25) (62) (77)	28 (19) (66) (67)
72 (3)	85 (19) (61) (67)	83 (21) (63) (69)	80 (25) (66) (77)	79 (20) (58) (68)	72 (21) (76) (69)	78 (26) (63) (79)	38 (22) (64) (71)
96 (4)	77 (23) (73) (73)	83 (28) (62) (83)	82 (26) (63) (79)	77 (25) (62) (77)	--	--	--
120 (5)	85 (28) (62) (83)	87 (26) (60) (79)	83 (26) (63) (79)	77 (24) (73) (76)	--	--	--
144 (6)	85 (23) (65) (73)	81 (26) (59) (79)	81 (26) (66) (79)	79 (24) (73) (76)	--	--	--
Average for each Column	81 (22) (63) (71)	82 (25) (58) (77)	79 (26) (64) (78)	74 (22) (65) (72)	72 (22) (67) (72)	69 (24) (60) (75)	28 (22) (66) (72)

*Temperature and percent relative humidity are presented in brackets to help the reader evaluate the differences in amount of water removed from the [illegible] relative humidity [illegible]

TABLE 33

Summary
of
Average Hourly Evaporated Water Added to the
Ventilation Air During Different Rates of
Air Flow and Accumulation Time
Per Bird Housed

Hours (days)	Air Flow cm^3/sec (ft^3/min) 1836 (3.89)	1671 (3.54)	1473 (3.12)	1326 (2.81)	1071 (2.27)	845 (1.79)	0
	grams (grains)						
24 (1)	3.70 (57)	3.07 (47)	2.59 (40)	2.10 (32)	2.65 (41)	2.22 (34)	0.66 (10)
48 (2)	3.70 (57)	4.11 (63)	3.28 (51)	2.43 (38)	3.08 (48)	2.64 (41)	1.09 (17)
72 (3)	4.31 (67)	4.19 (65)	4.06 (63)	2.49 (38)	3.04 (47)	3.13 (48)	1.40 (22)
96 (4)	2.56 (39)	2.95 (46)	3.15 (49)	3.27 (50)	--	--	--
120 (5)	3.06 (47)	3.30 (51)	3.53 (54)	3.27 (50)	--	--	--
144 (6)	3.02 (47)	3.34 (52)	3.39 (52)	3.20 (49)	--	--	--
Average for each column	3.39 (52)	3.49 (54)	3.33 (51)	2.79 (43)	2.92 (45)	2.66 (41)	1.05 (16)

TABLE 34

Summary
of
Water Evaporated From the Manure Added to the Exhaust Air
at Different Rates of Flow and Accumulation Time

Hours (days)	Air Flow - m^3/sec (ft^3/min)						
	0.166 (351)	0.172 (365)	0.180 (380)	0.183 (388)	0.190 (403)	0.195 (412)	0.219 (464)
	grams/kg (grains/lb) of air (1)						
24 (1)	0.593 (4.15)	0.474 (3.32)	0.480 (3.36)	0.373 (2.61)	0.463 (3.24)	0.378 (2.65)	0.099 (0.69)
48 (2)	0.593 (4.15)	0.634 (4.44)	0.608 (4.26)	0.433 (3.03)	0.538 (3.77)	0.447 (3.13)	0.164 (1.15)
72 (3)	0.611 (4.28)	0.647 (4.53)	0.593 (4.15)	0.443 (3.10)	0.531 (3.72)	0.531 (3.72)	0.211 (1.48)
96 (4)	0.513 (3.60)	0.571 (4.00)	0.581 (4.07)	0.371 (4.01)	--	--	--
120 (5)	0.615 (4.31)	0.634 (4.44)	0.631 (4.42)	0.371 (4.01)	--	--	--
144 (6)	0.593 (4.15)	0.628 (4.40)	0.607 (4.25)	0.557 (3.90)	--	--	--
Average for each column	0.586 (4.11)	0.598 (4.19)	0.583 (4.09)	0.492 (3.44)	0.511 (3.58)	0.452 (3.17)	0.158 (1.11)

(1) Specific weight of air 1.202 kg/m^3 (0.075 lb/ft^3)

Appendix

Temperature and Heat Production
Per Pound (Kilogram) of Poultry, Live Weight (1)

Temperature		Total Heat		Sensible Heat	Latent Heat
°F	°C	btu/lb	kcal/kg	%	%
60	15.56	9.00	5.00	71	29
61	16.11	9.00	5.00	71	29
62	16.67	9.00	5.00	70	30
63	17.22	9.00	5.00	69	31
64	17.78	9.00	5.00	69	31
65	18.33	8.95	4.97	68	32
66	18.89	8.95	4.97	68	32
67	19.44	8.90	4.94	68	32
68	20.00	8.85	4.92	67	33
69	20.56	8.80	4.89	67	33
70	21.11	8.75	4.86	66	34
71	21.67	8.70	4.83	66	34
72	22.22	8.60	4.78	65	35
73	22.78	8.50	4.72	64	36
74	23.33	8.40	4.67	63	37
75	23.89	8.30	4.61	62	38
76	24.44	8.20	4.56	61	39
77	25.00	8.10	4.50	60	40
78	25.56	8.00	4.44	59	41
79	26.11	7.90	4.39	58	42
80	26.67	7.80	4.33	57	43
81	27.72	7.70	4.27	56	44
82	27.78	7.60	4.22	55	45
83	28.33	7.50	4.17	54	46
84	28.89	7.35	4.08	52	48
85	29.44	7.20	4.00	50	50

(1) Values in this table derived from calorimetric data by Ota & McNally.

Appendix

WEST VIRGINIA UNIVERSITY
Agricultural Engineering

Conversion Factors

To Convert	Multiply By	To Obtain
Specific Volume		
cubic feet/pound	0.0624	cubic meters/kilogram
cubic meters/kilogram	16.0256	cubic feet/pound
Moisture Content		
grains/pound	0.1428	grams/kilogram
grams/kilogram	7.0028	grains/pound
Bird Heat Production		
Btu/pound	.5556	kilogram calories/kilogram
kilogram calories/kilogram	1.8000	Btu/pound
Heat of Vaporization		
Btu/pound	.5556	kilogram calories/kilogram
kilogram calories/kilogram	1.8000	Btu/pound
Moisture		
grains	0.0648	grams
grams	15.4321	grains

Heat of Vaporization Used in this Research

1100 Btu/pound equals 611 kilogram calories/kilogram

Enthalpy		
Btu/pound	0.5556 (Btu)-4.2667	kilogram-calories/kilogram
kilogram calories/kilogram	1.8 (kcal + 4.2667)	Btu/pound

Moisture Content in Latent Heat of Respiration

btus	6.3636	grains
kilocalories	1.6367	grams